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Supporting Information

Catalytic Enantioselective Synthesis of Naturally Occurring Butenolides Combining *hetero-Allylic* Alkylation and Ring Closing Metathesis

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1. General Remarks

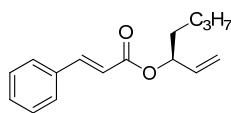
All reactions were carried out under a nitrogen atmosphere using flame dried glassware. All the ligands and $\text{CuBr}\cdot\text{SMe}_2$ were purchased from Aldrich and used without further purification. Grignard reagents were prepared from the corresponding alkyl bromides and magnesium turnings in Et_2O following standard procedures. Grignard reagents were titrated using *s*-BuOH and catalytic amounts of 1,10-phenanthroline. Solvents were purified before use employing standard techniques.¹

Chromatography: Merck silica gel type 9385 230-400 mesh, TLC: Merck silica gel 60, 0.25 mm. Components were visualized by staining with a solution of a mixture of KMnO_4 (10 g) and K_2CO_3 (10 g) in H_2O (500 mL). Progress and conversion of the reaction were determined by GC-MS (GC, HP6890; MS HP5973) with an HP1 or HP5 column (Agilent Technologies, Palo Alto, CA) or by ^1H -NMR spectroscopy. Mass spectra were recorded on a AEI-MS-902 mass spectrometer. All ^1H NMR and ^{13}C NMR/APT spectra were recorded on Varian Mercury Plus (400 MHz) spectrometer using CDCl_3 as solvent. Chemical shift values are reported in ppm with the solvent resonance as the internal standard (CHCl_3 : δ 7.26 for ^1H , δ 77.0 for ^{13}C). Data are reported as follows: chemical shifts, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, br = broad, m = multiplet), coupling constants (Hz), and integration. Melting points were determined on a Buchi B-545 melting point apparatus. Optical rotations were measured on a *Schmidt + Haensch* polarimeter (Polartronic MH8) with a 10 cm cell (*c* given in g/100 mL). Enantioselectivities were determined by HPLC analysis using a Shimadzu LC-10ADVP HPLC equipped with a Shimadzu SPD-M10A/VP diode array detector.

2. Experimental Section

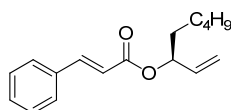
2.1 General procedure for copper catalyzed *hetero-allylic asymmetric alkylation*:²

Starting material **1** was synthesized according to the procedure of Trombini and Lombardo et al.³ The Grignard reagent (2–3 equiv in Et₂O) was added dropwise over 5 min to a homogeneous, stirred and cooled (–75 °C or –55 °C) solution of the allylic bromide **1** (303 mg, 1.12 mmol), CuBr·SMe₂ (6.7 mg, 3 mol%) and (*R,R*)-(+)-TaniaPhos (27.7 mg, 3.6 mol%) in CH₂Cl₂ (3.5 mL) under a nitrogen atmosphere. NMR or TLC analysis showed the reaction had reached completion (typically overnight) and the reaction was quenched with MeOH (5 mL). The reaction mixture was removed from the cooling bath and sat. aq. NH₄Cl (5 mL) was added. The mixture was partitioned between CH₂Cl₂ (5 mL) and water. The organic layer was dried (MgSO₄), filtered and the solvent evaporated *in vacuo*. Purification by flash chromatography over silica gel, using Et₂O/*n*-Pentane 1% to 2% to afford the product **2** as colorless oils in good to excellent yield (78%–91%).



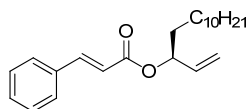
2.1.1 (+)-(S)-hept-1-en-3-yl cinnamate (**2a**)

Colorless oil, 91% yield. $[\alpha]_D^{20} = +32.6$ (*c* 0.2, CHCl₃). ¹H NMR (400 MHz, CDCl₃) δ 7.71 (d, *J* = 16.0 Hz, 1H), 7.52 (dd, *J* = 6.7, 3.0 Hz, 2H), 7.43–7.31 (m, 3H), 6.47 (d, *J* = 16.0 Hz, 1H), 5.86 (s, 1H), 5.39 (dd, *J* = 13.3, 6.2 Hz, 1H), 5.31 (dd, *J* = 9.9, 8.6 Hz, 1H), 5.19 (dd, *J* = 10.5, 1.1 Hz, 1H), 1.88–1.52 (m, 2H), 1.50–1.08 (m, 4H), 1.01–0.65 (m, 3H). ¹³C NMR (100.6 MHz, CDCl₃) δ 166.1(s), 144.7(d), 136.5(d), 134.3(s), 130.1(d), 128.8(d), 128.0(d), 118.3(d), 116.4(t), 74.8(d), 33.9(t), 27.2(t), 22.4(t), 13.9(q). HRMS (ESI, *m/z*): calcd for C₁₆H₂₀O₂ [M]⁺: 244.1463; found: 244.1469. The configuration and enantioselectivity were determined after conversion to compound **3a**.



2.1.2 (+)-(S)-hept-1-en-3-yl cinnamate (**2b**)

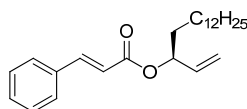
Colorless oil, 89% yield. $[\alpha]_D^{20} = +31.1$ (*c* 0.26, CHCl₃). ¹H NMR (400 MHz, CDCl₃) δ 7.70 (d, *J* = 16.0 Hz, 1H), 7.57–7.47 (m, 2H), 7.39 (dd, *J* = 4.9, 1.7 Hz, 3H), 6.46 (d, *J* = 16.0 Hz, 1H), 5.85 (ddd, *J* = 16.9, 10.5, 6.3 Hz, 1H), 5.38 (dt, *J* = 12.4, 6.2 Hz, 1H), 5.29 (dt, *J* = 17.3, 1.3 Hz, 1H), 5.22–5.14 (m, 1H), 1.83–1.58 (m, 2H), 1.46–1.09 (m, 6H), 0.89 (t, *J* = 6.9 Hz, 3H). ¹³C NMR (100.6 MHz, CDCl₃) δ 166.3(s), 144.7(d), 136.7(d), 134.5(s), 130.2(d), 128.8(d), 128.0(d), 118.4(d), 116.5(t), 74.9(d), 34.3(t), 31.6(t), 24.7(t), 22.5(t), 14.0(q). HRMS (ESI, *m/z*): calcd for C₁₇H₂₂O₂ [M]⁺: 258.1620; found: 258.1606. The configuration and enantioselectivity were determined after conversion to compound **3b**.



2.1.3 (+)-(S)-tetradec-1-en-3-yl cinnamate (**2c**)

The reaction was performed at –55 °C with 3 equiv of Grignard reagent. Colorless oil, 84% yield.

$[\alpha]_D^{20} = +13.1$ (*c* 1.7, CHCl₃). ¹H NMR (400 MHz, CDCl₃): δ 7.70 (d, *J* = 16.0 Hz, 1H), 7.53 (dd, *J* = 6.5, 3.0 Hz, 2H), 7.38 (dd, *J* = 6.4, 3.5 Hz, 3H), 6.43 (dd, *J* = 43.9, 27.9 Hz, 1H), 5.85 (ddd, *J* = 17.2, 10.5, 6.3 Hz, 1H), 5.37 (q, *J* = 6.6 Hz, 1H), 5.29 (d, *J* = 17.2 Hz, 1H), 5.19 (d, *J* = 10.5 Hz, 1H), 1.78-1.61 (m, 2H), 1.44-1.04 (m, 18H), 0.88 (dd, *J* = 8.0, 5.6, 3H). ¹³C NMR (75 MHz, CDCl₃) δ 166.5, 144.9, 136.9, 134.7, 130.4, 129.1, 128.3, 118.7, 116.7, 75.1, 34.5, 32.1, 29.9, 29.8, 29.7, 29.6, 29.6, 25.3, 22.9, 14.3. HRMS (ESI+, *m/z*): calcd for C₂₃H₃₄O₂Na [M+Na]⁺: 365.2451; found: 365.2440. The configuration and enantioselectivity were determined after conversion to compound **3c**.



2.1.4 (+)-(S)-hexadec-1-en-3-yl cinnamate (**2d**)

The reaction was performed at -55 °C with 3 equiv of Grignard reagent. Colorless oil, 78% yield. $[\alpha]_D^{20} = +12.9$ (*c* 0.2, CHCl₃). ¹H NMR (400 MHz, CDCl₃) δ 7.71 (d, *J* = 16.0 Hz, 1H), 7.52 (dd, *J* = 6.5, 3.0 Hz, 2H), 7.43-7.32 (m, 3H), 6.47 (d, *J* = 16.0 Hz, 1H), 5.86 (ddd, *J* = 17.2, 10.5, 6.3 Hz, 1H), 5.40 (dd, *J* = 13.0, 6.6 Hz, 1H), 5.30 (d, *J* = 17.2 Hz, 1H), 5.19 (d, *J* = 10.5 Hz, 1H), 1.80-1.54 (m, 2H), 1.30 (m, 20H), 0.89 (t, *J* = 6.8 Hz, 3H). ¹³C NMR (100.6 MHz, CDCl₃) δ 166.1(s), 144.5(d), 136.7(d), 134.4(s), 130.1(d), 128.7(d), 127.9(d), 118.3(d), 116.4(t), 74.8(d), 34.2(t), 31.9(t), 29.6(t), 29.6(t), 29.6(t), 29.5(t), 29.5(t), 29.3(t), 29.3(t), 25.0(t), 22.6(t), 14.0(q). HRMS (ESI, *m/z*): calcd for C₂₅H₃₈O₂ [M]⁺: 370.2872; found: 370.2856. The configuration and enantioselectivity were determined after conversion to compound **3d**.

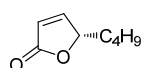
2.2 Synthesis of Racemic γ -butenolides:

Racemic γ -butenolides were synthesized according to literature.⁴

Typical procedure: 2-trimethylsilyloxyfuran (1 mmol) and alkyl iodide (1.3 mmol) were added to a suspension of AgOOCF₃ (1.3 mmol) in dry CH₂Cl₂ (2.5 mL) with stirring under N₂ at -78 °C. The temperature was slowly increased to 20 °C over 4h and the mixture was filtered through celite. Purification by flash chromatography gave the racemic γ -butenolides.

2.3 General procedure for ring closing metathesis (RCM):

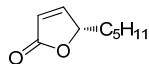
Allylic bromide **2** (0.7 mmol) was dissolved in degassed CH₂Cl₂ (3.5 mL) under N₂ atmosphere. Hoveyda-Grubbs 2nd generation catalyst (0.021 mmol) was tipped into the solution and then the stirred solution was refluxed for 24-40 h at 40 °C. The mixture was cooled down to room temperature and the solvents were removed under reduced pressure. Purification by flash chromatography (*n*-Pentane/Ether = 4/1) afforded the product.



2.3.1 (+)-(S)-5-butylfuran-2(5H)-one (**3a**)

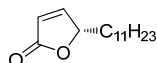
Colorless oil, 83% yield. $[\alpha]_D^{25} = +103.5$ (*c* 0.7, CHCl₃). 97% ee was determined by HPLC analysis (Chiral OJ-H column, heptane/*i*-PrOH 95:5, 0.5 mL/min, 210 nm). Retention time: *t*_{major} = 17.40 and *t*_{minor} = 18.34 min. ¹H NMR (400 MHz, CDCl₃) δ 7.45 (dd, *J* = 5.7, 1.5 Hz, 1H), 6.11 (dd, *J* = 5.7, 2.0 Hz, 1H), 5.04 (ddt, *J* = 7.3, 5.4, 1.7 Hz, 1H), 1.82-1.60 (m, 2H), 1.50-1.28 (m,

4H), 0.91 (dd, $J = 14.4, 7.2$ Hz, 3H). ^{13}C NMR (100.6 MHz, CDCl_3) δ 173.0 (s), 156.4 (d), 121.2 (d), 83.3 (d), 32.7 (t), 26.9 (t), 22.2 (t), 13.6 (q). HRMS (ESI, m/z): calcd for $\text{C}_8\text{H}_{12}\text{O}_2$ $[\text{M}]^+$: 140.0837; found: 140.0835. The absolute configuration was established by correlation to lit.⁵ $[\alpha]_{\text{D}}^{22} = +100.4$ (c 1.01, CHCl_3).



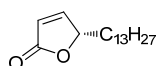
2.3.2 (+)-(S)-5-pentylfuran-2(5H)-one (3b)

Colorless oil, 82% yield. $[\alpha]_{\text{D}}^{25} = +97.0$ (c 0.6, CHCl_3). 98% ee was determined by HPLC analysis (Chiral AS-H column, heptane/*i*-PrOH 95:5, 0.5 mL/min, 210 nm). Retention time: $t_{\text{major}} = 19.52$ and $t_{\text{minor}} = 22.33$ min. ^1H NMR (400 MHz, CDCl_3) δ 7.57-7.38 (m, 1H), 6.04 (dd, $J = 5.7, 2.0$ Hz, 1H), 4.99 (dd, $J = 7.3, 5.5$ Hz, 1H), 1.67 (m, 2H), 1.49-1.21 (m, 6H), 0.85 (t, $J = 7.1$ Hz, 3H). ^{13}C NMR (100.6 MHz, CDCl_3) δ 173.1 (s), 156.4 (d), 121.2 (d), 83.3 (d), 33.0 (t), 31.3 (t), 24.5 (t), 22.3 (t), 13.8 (q). HRMS (ESI, m/z): calcd for $\text{C}_9\text{H}_{14}\text{O}_2$ $[\text{M}]^+$: 154.0994; found: 154.0987. The absolute configuration was established by correlation to lit.⁵ $[\alpha]_{\text{D}}^{25} = +94$ (c 1.05, CHCl_3).



2.3.3 (+)-(S)-5-undecylfuran-2(5H)-one (3c)

White wax, 84% yield. $[\alpha]_{\text{D}}^{20} = +47.5$ (c 0.8, CHCl_3). 98% ee determined by HPLC analysis (Chiral OB-H column, heptane/*i*-PrOH 95:5, 0.5 mL/min, 210 nm). Retention time: $t_{\text{major}} = 12.17$ and $t_{\text{minor}} = 13.15$ min. ^1H NMR (400 MHz, CDCl_3) δ 7.45 (dd, $J = 5.7, 1.5$ Hz, 1H), 6.09 (dd, $J = 5.7, 1.9$ Hz, 1H), 5.03 (ddd, $J = 5.6, 3.5, 1.6$ Hz, 1H), 1.83-1.58 (m, 2H), 1.51-1.09 (m, 18H), 0.87 (t, $J = 6.3$ Hz, 3H). ^{13}C NMR (100.6 MHz, CDCl_3) δ 173.1 (s), 156.3 (d), 121.4 (d), 83.4 (d), 33.2 (t), 31.9 (t), 29.5 (t), 29.4 (t), 29.3 (t), 29.3 (t), 29.3 (t), 24.9 (t), 22.6 (t), 14.1 (q). HRMS (ESI, m/z): calcd for $\text{C}_{15}\text{H}_{27}\text{O}_2$ $[\text{M}]^+$: 239.2006; found: 239.2003. The absolute configuration was established by correlation to lit.⁶ $[\alpha]_{\text{D}}^{22} = -66.6$ ($c = 1.95$, CHCl_3).



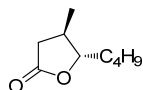
2.3.4 (+)-(S)-5-tridecylfuran-2(5H)-one (3d)

White wax, 82% yield. $[\alpha]_{\text{D}}^{20} = +53$ (c 1.05, CHCl_3). 97% ee determined by HPLC analysis (Chiral OB-H column, heptane/*i*-PrOH 95:5, 0.5 mL/min, 210 nm). Retention time: $t_{\text{major}} = 10.71$ and $t_{\text{minor}} = 11.77$ min. ^1H NMR (400 MHz, CDCl_3) δ 7.44 (dd, $J = 5.7, 1.4$ Hz, 1H), 6.07 (dd, $J = 5.7, 2.0$ Hz, 1H), 5.01 (ddd, $J = 5.5, 3.4, 1.5$ Hz, 1H), 1.81-1.56 (m, 2H), 1.45-1.11 (m, 20H), 0.85 (t, $J = 6.8$ Hz, 3H). ^{13}C NMR (100.6 MHz, CDCl_3) δ 173.1 (s), 156.3 (d), 121.4 (d), 83.4 (d), 33.1 (t), 31.8 (t), 29.6 (t), 29.6 (t), 29.5 (t), 29.4 (t), 29.3 (t), 29.3 (t), 29.2 (t), 24.9 (t), 22.6 (t), 14.0 (q). HRMS (ESI, m/z): calcd for $\text{C}_{17}\text{H}_{31}\text{O}_2$ $[\text{M}]^+$: 267.2319; found: 267.2318. The absolute configuration was established by correlation to lit.⁶ $[\alpha]_{\text{D}}^{25} = -56.6$ ($c = 2.285$, CHCl_3).

2.4 General procedure for synthesis of (-)-whiskey lactone and (-)-cognac lactone^{6,7}:

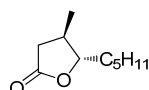
A solution of methyllithium (1.6 M) in ether (1.25 mL) was slowly added to a suspension of CuI (190.4 mg, 1 mmol) in Et_2O (2.5 mL) at -20°C . The resulting mixture was cooled to -60°C before a solution of substrate (0.2 mmol) in ether (2 mL) was added dropwise. After stirring at -60°C

over 2h, the reaction mixture was quenched with aq. HCl (1.0 M, 3 mL) and filtered over Celite. The organic layer was separated and the aqueous layer was extracted with Et₂O (3×5 mL). The combined organic layer were washed with sat. NaHCO₃ and dried over Na₂SO₄ and concentrated. The residue was purified by flash chromatography (*n*-Pentane/Ether = 4/1).



2.4.1 (-)-(4R,5S)-5-butyl-4-methyldihydrofuran-2(3H)-one (4a)

Colorless oil, 93% yield. $[\alpha]_D^{20} = -83.3$ (*c* 0.17, CHCl₃). ¹H NMR (400 MHz, CDCl₃) δ 4.00 (td, *J* = 8.1, 3.8 Hz, 1H), 2.73-2.56 (m, 1H), 2.30-2.07 (m, 2H), 1.75-1.27 (m, 6H), 1.13 (d, *J* = 6.4 Hz, 3H), 0.91 (t, *J* = 7.2 Hz, 3H). ¹³C NMR (100.6 MHz, CDCl₃) δ 176.6 (s), 87.4 (d), 37.1 (t), 36.1 (d), 33.7 (t), 27.8 (t), 22.5 (t), 17.5 (q), 13.9 (q). HRMS (ESI+, *m/z*): calcd for C₉H₁₇O₂ [M+H]⁺: 157.1223; found: 157.1210. The absolute configuration was established by correlation to lit.⁷ $[\alpha]_D^{25} = +84.5$ (*c* = 2.13, MeOH).

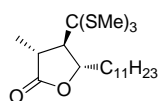


2.4.2 (-)-(4R,5S)-4-methyl-5-pentyldihydrofuran-2(3H)-one (4b)

Colorless oil, 96% yield. $[\alpha]_D^{20} = -73.4$ (*c* 0.22, CHCl₃). ¹H NMR (400 MHz, CDCl₃) δ 4.00 (td, *J* = 7.8, 4.0 Hz, 1H), 2.75-2.54 (m, 1H), 2.32-2.06 (m, 2H), 1.75-1.21 (m, 9H), 1.13 (d, *J* = 6.4 Hz, 3H), 0.89 (t, *J* = 7.0 Hz, 3H). ¹³C NMR (100.6 MHz, CDCl₃) δ 176.6 (s), 87.4 (d), 37.1 (t), 36.0 (d), 33.9 (t), 31.5 (t), 25.4 (t), 22.5 (t), 17.4 (q), 14.0 (q). HRMS (ESI+, *m/z*): calcd for C₁₀H₁₈O₂Na [M+Na]⁺: 193.1199; found: 193.1185. The absolute configuration was established by correlation to lit.⁷ $[\alpha]_D^{25} = +82.2$ (*c* = 0.71, MeOH).

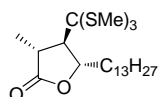
2.5 General procedure for the synthesis of (-)-nephrosteranic acid and (-)-roccellaric acid⁶

To a stirred solution of (MeS)₃CH (58.5 μ L, 0.44 mmol) in THF (1.5 mL) was added *n*-BuLi (1.7 M, 275 μ L, 0.44 mmol) in hexane at -78 °C. After being stirred for 1h, a solution of butenolide (0.4 mmol) in 1 mL THF was slowly added to the mixture at -78 °C over 15 min. The mixture was stirred for 3h, then the reaction was quenched by sat. aq. NH₄Cl. The reaction mixture was extracted by EtOAc (3×5 mL) and dried over Na₂SO₄ and concentrated. A solution of NaHMDS (1 M, 0.88 mL, 0.88 mmol) in THF was dropwise added to the crude mixture dissolved in THF (4 mL) at -78 °C. After stirring for 1 h at -78 °C, MeI (249 μ L, 4 mmol) was added slowly to the reaction mixture. The reaction mixture was stirred for 3 h before increasing the temperature from -78 °C to r.t. Then the reaction was quenched by adding sat. aq. NH₄Cl and EtOAc. The organic phase was separated, and the aqueous phase was extracted with EtOAc (3×5 mL). The combined phases were dried over MgSO₄ and concentrated. Flash chromatography (*n*-Pentane/Ether = 5/1) gave the product **5**.



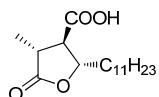
2.5.1 (3R,4R,5S)-3-methyl-4-(tris(methylthio)methyl)-5-undecyldihydrofuran-2(3H)-one (5c)

Colorless oil, 86% yield. $[\alpha]_D^{20} = -13.6$ (c 0.25, CHCl_3). ^1H NMR (400 MHz, CDCl_3) δ 4.75-4.57 (m, 1H), 3.12-2.98 (m, 1H), 2.29 (td, $J = 3.7, 1.9$ Hz, 1H), 2.22-2.13 (m, 9H), 1.70-1.46 (m, 2H), 1.41 (dd, $J = 7.7, 1.9$ Hz, 3H), 1.25 (m, 18H), 0.87 (t, $J = 6.9$ Hz, 3H). ^{13}C NMR (100.6 MHz, CDCl_3) δ 179.3, 80.6, 73.1, 57.5, 39.1, 38.3, 31.9, 29.6, 29.6, 29.5, 29.4, 29.3, 29.1, 25.7, 22.7, 19.1, 14.1, 13.8. HRMS (ESI+, m/z): calcd for $\text{C}_{20}\text{H}_{38}\text{O}_2\text{S}_3\text{Na}$ $[\text{M}+\text{Na}]^+$: 429.1926; found: 429.1921.



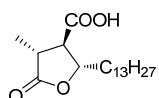
2.5.2 (-)-(3R,4R,5S)-3-methyl-4-(tris(methylthio)methyl)-5-undecyldihydrofuran-2(3H)-one (5d) Colorless oil, 84% yield. $[\alpha]_D^{20} = -11.0$ (c 1.0, CHCl_3). ^1H NMR (400 MHz, CDCl_3) δ 4.73-4.54 (m, 1H), 3.06 (qd, $J = 7.7, 3.8$ Hz, 1H), 2.29 (t, $J = 3.5$ Hz, 1H), 2.18 (s, 9H), 1.70-1.46 (m, 2H), 1.41 (d, $J = 7.7$ Hz, 3H), 1.25 (s, 22H), 0.87 (t, $J = 6.8$ Hz, 3H). ^{13}C NMR (100.6 MHz, CDCl_3) δ 179.3, 80.6, 73.1, 57.6, 39.2, 38.3, 31.9, 29.7, 29.6, 29.6, 29.5, 29.4, 29.3, 29.1, 25.7, 22.7, 19.1, 14.1, 13.8. HRMS (ESI+, m/z): calcd for $\text{C}_{22}\text{H}_{42}\text{O}_2\text{S}_3\text{Na}$ $[\text{M}+\text{Na}]^+$: 457.2239; found: 457.2206.

$\text{BF}_3 \cdot \text{OEt}_2$ (140 μL , 1.11 mmol) was added dropwise to a suspension of trisubstituted lactone (0.074 mmol) and HgO (80 mg, 0.368 mmol) in $\text{THF}/\text{H}_2\text{O}$ (4:1, 1 mL). After stirring at room temp. for 23 h, H_2O (2 mL) and EtOAc (2 mL) were added. The organic solvent was separated. The aqueous solution was extracted with EtOAc (5 mL) for three times. The combined organic phases were washed with brine and dried over MgSO_4 , and the solvent was removed by rotary evaporation. Flash chromatography (n -Pentane/Ether 1/1 to 1/4) gave the product **6**.



2.5.3 (-)-(2S,3R,4R)-4-methyl-5-oxo-2-undecyltetrahydrofuran-3-carboxylic acid, nephrosteranic acid (6c)

Colorless solid, 97% yield. $[\alpha]_D^{20} = -27.2$ (c 1.05, CHCl_3), lit.:⁸ $[\alpha]_D^{20} = -27.7$ (c 0.90, CHCl_3). $m.p.$ 106-107 $^\circ\text{C}$. ^1H NMR (400 MHz, CDCl_3) δ 4.47 (tt, $J = 10.5, 5.3$ Hz, 1H), 2.98 (dd, $J = 11.4, 7.1$ Hz, 1H), 2.70 (dd, $J = 11.3, 9.5$ Hz, 1H), 1.95-1.62 (m, 2H), 1.38 (dt, $J = 21.7, 9.7$ Hz, 3H), 1.32-1.16 (m, 18H), 0.88 (t, $J = 6.9$ Hz, 3H). ^{13}C NMR (100.6 MHz, CDCl_3) δ 176.6 (s), 176.0 (s), 79.3 (d), 53.9 (d), 39.8 (d), 34.9 (t), 31.9 (t), 29.6 (t), 29.5 (t), 29.4 (t), 29.3 (t), 29.2 (t), 25.3 (t), 22.7 (t), 14.5 (q), 14.1 (q). HRMS (ESI+, m/z): calcd for $\text{C}_{17}\text{H}_{30}\text{O}_4\text{Na}$ $[\text{M}+\text{Na}]^+$: 321.2036; found: 321.2029.



2.5.4 (-)-(2S,3R,4R)-4-methyl-5-oxo-2-tridecyltetrahydrofuran-3-carboxylic acid, roccellaric acid (6d)

Colorless crystals, 94% yield. $[\alpha]_D^{20} = -24.3$ (c 0.6, CHCl_3), lit.:⁸ $[\alpha]_D^{20} = -26$ (c 0.5, CHCl_3). $m.p.$

108-110 °C. ¹H NMR (400 MHz, CDCl₃) δ 4.48 (dd, *J* = 9.2, 4.0 Hz, 1H), 2.98 (dq, *J* = 11.3, 7.1 Hz, 1H), 2.70 (dd, *J* = 11.4, 9.4 Hz, 1H), 1.92-1.60 (m, 2H), 1.47-1.17 (m, 25H), 0.88 (t, *J* = 6.8 Hz, 3H). ¹³C NMR (100.6 MHz, CDCl₃) δ 176.7(s), 175.1(s), 79.3(d), 53.8(d), 39.8(d), 34.9(t), 31.9(t), 29.7(t), 29.6(t), 29.6(t), 29.5(t), 29.4(t), 29.3(t), 29.2(t), 25.3(t), 22.7(t), 14.5(q), 14.1(q). HRMS (ESI-, *m/z*): calcd for C₁₉H₃₃O₄ [M-H]⁻: 325.2373; found: 325.2379.

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4. ^1H NMR and ^{13}C NMR/APT Spectra of compounds

